Aeroacoustics 2000 Highlights

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Significant advances in aeroacoustic research have been made over the past year in commercial subsonic aircraft noise reduction, noise assessments for tilt-rotor aircraft, and use of acoustics/flow control methods to improve weapons deployment for military aircraft. However, with the cancellation of NASA's High Speed Research Program, supersonic aircraft noise reduction research has been considerably reduced.

XV-15 low noise terminal area operations flight tests were conducted in October 1999 by the NASA/Army/Bell Helicopter test team to develop safe, low noise terminal area flight procedures for tilt-rotor aircraft. For cabin noise, the United Technologies Research Center (UTRC) analytically extended a Statistical Energy Analysis technique and applied it to panels from the Sikorsky S-92 helicopter.

Airframe noise studies in NASA Langley's Quiet Flow Facility has provided validation that shear layer instability and related pressure scatter is a dominant flap-edge noise mechanism.

Jet noise continues to be a major concern for aircraft. A new anechoic supersonic heated jet facility was constructed at Florida State University under the sponsorship of Office of Naval Research. Research at the University of California Irvine has demonstrated substantial noise reduction from supersonic jets by enveloping the lower part of the jet with a parallel stream of air. UCLA continued identifying and modeling jet noise mechanisms using first-principles computations. The Ohio State University performed research for jet noise investigating far field and flow visualizations using laser sheet lighting in an attempt to identify noise sources. UTRC obtained a comprehensive acoustic and flow field database for subsonic jets, and developed a procedure for extrapolating model scale noise reduction concepts to full scale Perceived Noise Levels. UTRC also studied jet noise sources with a linear phased array and turbulence flow measurement probes.

General Electric (GE) Aircraft Engines has made considerable progress in the past year developing the "chevron" nozzle concept for application to GE/CFMI engines. Results obtained thus-far from static engine tests have been very positive, with jet noise reduction benefits of as much as 3.5 EPNdB demonstrated on a component basis, yielding a net engine system benefit of ~2.5 EPNdB at takeoff certification conditions.

NASA Glenn's model fan research included a rotor-alone noise assessment using a self-centering nacelle suspension system that successfully maintained stringent fan tip clearances. A comprehensive database including turbulence measurements near the fan and unsteady surface pressures on stators were also obtained. A three-dimensional unsteady aerodynamic analysis code (LINFLUX) has been developed by UTRC, Pratt & Whitney and NASA for fan noise prediction. NASA Glenn, NASA Langley, Honeywell, and Boeing conducted acoustic modal measurements in the aft-fan duct of a Honeywell

TFE731-60 engine. Three innovative measurements techniques were applied: a rotating rake from NASA Glenn, in-duct microphones arrays from NASA Langley, and an external "cage array" from Boeing. The CDUCT code, developed by Boeing under NASA funding, models the acoustics of realistic three-dimensional engine fan ducts with acoustic liners. Improvements have also been made to Langley's TBIEM3D duct propagation code to include forward flight effects and modeling of segmented acoustic liners. Progress has been made by Langley and university partners explaining why bias flow liners can outperform an optimal passive liner for broadband noise reduction.

Combustion Research & Flow Technology, Inc. (CRAFT Tech), CALSPAN at The University of Buffalo, and The University of Mississippi, conducted a numerical/experimental study on interceptor missile vibrations with side steering control jets. Under AFOSR sponsorship, CRAFT Tech and the National Center for Physical Acoustics at University of Mississippi designed an Active Flow Control technique for attenuation of flow induced pressure oscillations in aircraft internal weapons bay.

Boeing Commercial Airplane Group

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Optimization of Engine Aft Fan Duct Acoustic Linings

The CDUCT code developed by Boeing under NASA AST contract models the acoustics of realistic three-dimensional engine fan ducts by means of parabolic approximation to the convected Helmholtz equation. With this approximation, the important frequency range can be modeled, accounting for flow, geometry, and acoustic lining effects using only an engineering workstation. Figure 1 illustrates the propagation of a mode through a typical fan duct with inner and outer walls treated. The direction of wave propagation is angled toward the upper bifurcation. Design studies are underway, seeking superior acoustic performance via optimization of the axial distribution of lining properties.

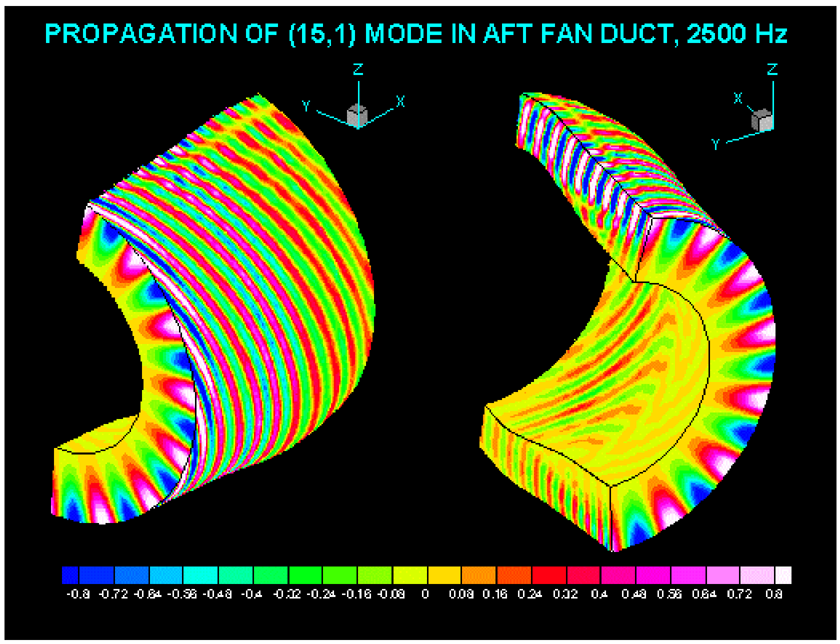
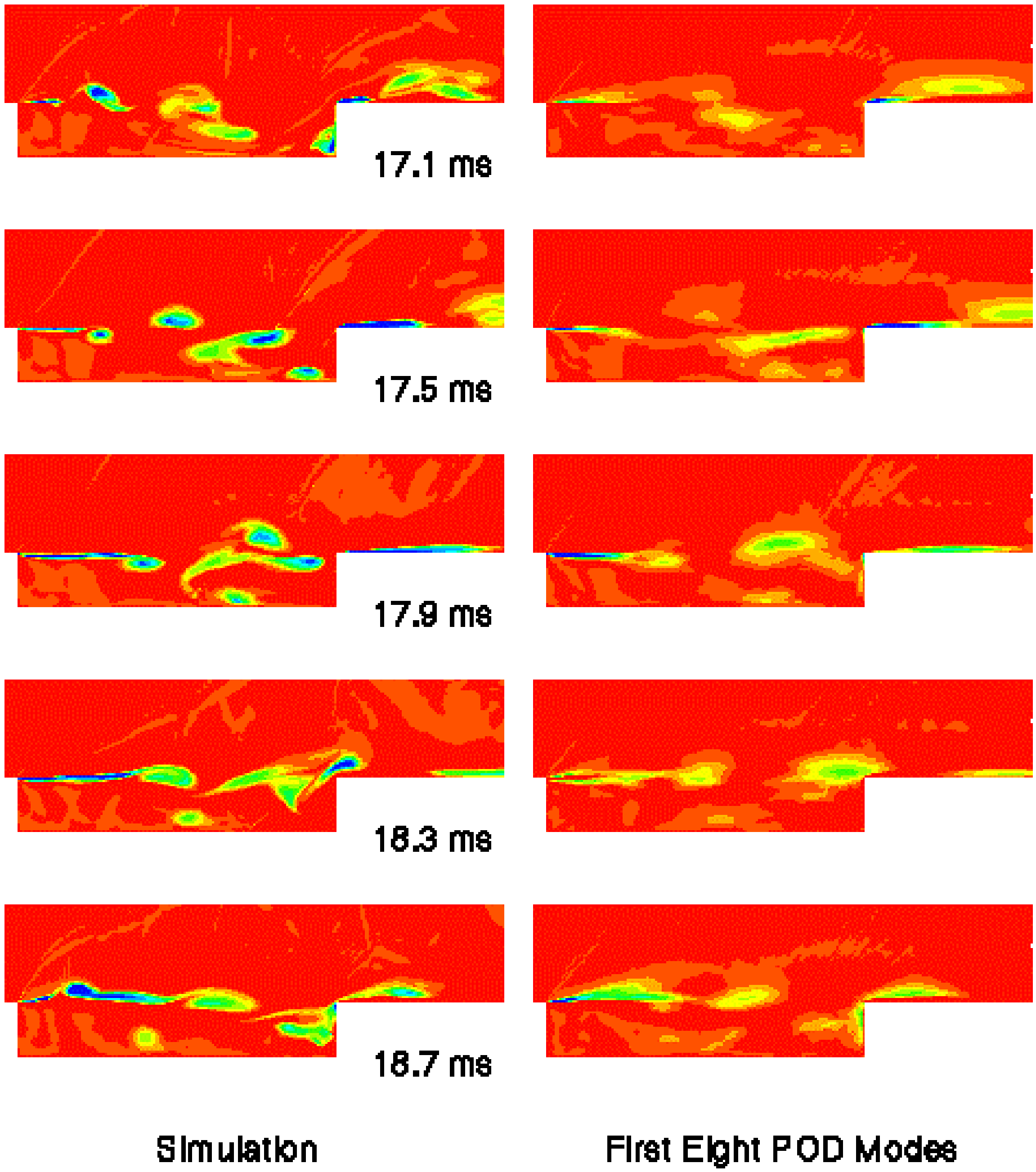


Figure 1 - Noise Propagation in Three Dimensional Aft Fan Duct

CRAFT Tech, Inc.

Contact: Neeraj Sinha (sinha@craft-tech.com)

Under AFOSR sponsorship, Combustion Research & Flow Technology, Inc. (CRAFT Tech) & National Center for Physical Acoustics (NCPA) at University of Mississippi are designing an Active Flow Control technique for attenuation of flow induced pressure oscillations in aircraft internal weapons bay. The active control method is based upon utilization of Proper Orthogonal Decomposition (POD) to design a Low Dimensional Flow Controller. The flow control model is derived by projection of the Navier Stokes equations upon POD modes extracted from high resolution Large Eddy Simulation (LES) of the cavity flowfield. The numerical modeling is being complemented by optical diagnostics including three-component PIV, Phase-Averaged Schlieren, etc. to provide direct correlation of turbulence spectra with pressure fluctuations. The figure below shows LES predictions of vortex shedding phenomena during a typical flow oscillation cycle in a cavity and is compared with the corresponding POD reconstruction of the transient vorticity field. The reconstruction was performed using only 8 POD modes and appears to have sufficient fidelity for evaluating application of candidate active control strategies.



LES Predictions and POD Reconstruction of Vortex Shedding during a flow oscillation cycle in a rectangular cavity (L/D=6 at Mach=1.5)

Florida State University

Contact: Anjaneyulu Krothapalli (kroth@fmrl.fsu.edu)

A new anechoic supersonic heated jet facility was constructed at Florida State University to investigate the supersonic jet noise of high temperature jets. The facility uses a SUE burner providing jet stagnation temperatures up to 1400 K at a jet exit Mach number of 2.5. The nozzle exit diameters can be up to 5 cm. The jet exhausts into an anechoic room measuring 6m x 6m x 4.5m. The facility was constructed under the sponsorship of Office of Naval Research.

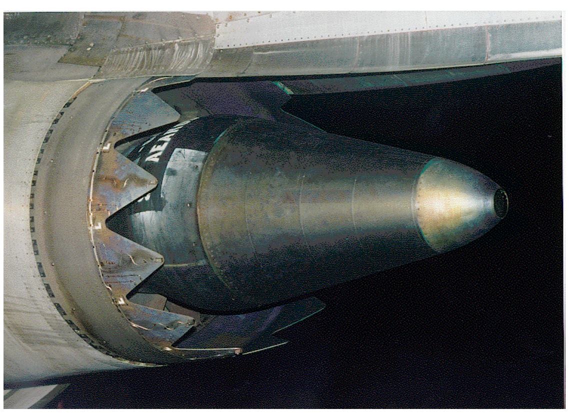
General Electric Aircraft Engines

Contact: Philip.Gliebe@ae.ge.com

GEAE has made considerable progress in the past year in developing the chevron nozzle concept for application to GE/CFMI engines. Over 50 chevron nozzle designs have been tested in GE's Cell 41 Anechoic Free Jet Scale Model Test Facility, to characterize and screen various design parameter effects on jet mixing noise for CF6, CFM56 and CF34 engine models. Results obtained thus far have been very positive, with jet noise reduction benefits of as much as 3.5 EPNdB demonstrated on a component basis, yielding a net engine system benefit of ~2.5 EPNdB at takeoff certification conditions. Wind tunnel performance testing of these chevron nozzles has demonstrated a minimal performance impact.

GEAE has conducted full-scale engine validation of the designs developed through scale model testing in Cell 41. Engine test results confirmed the measured scale model test acoustic benefits and performance impact, and were essential in verifying mechanical integrity in a real engine environment. Figure 1 below shows the full-scale engine test nozzles tested for two engine models. This work is a good example of successfully taking NASA AST Program Noise Reduction technology previously demonstrated as a concept in model scale, transitioning it to full scale engine design, and successfully demonstrating the concept benefits. This required addressing many difficult technical issues unique to engine application, in order to make the simple model concept demonstration become a reality on an engine system.

Static Engine Tests of Chevron Nozzles



CF6-80C2

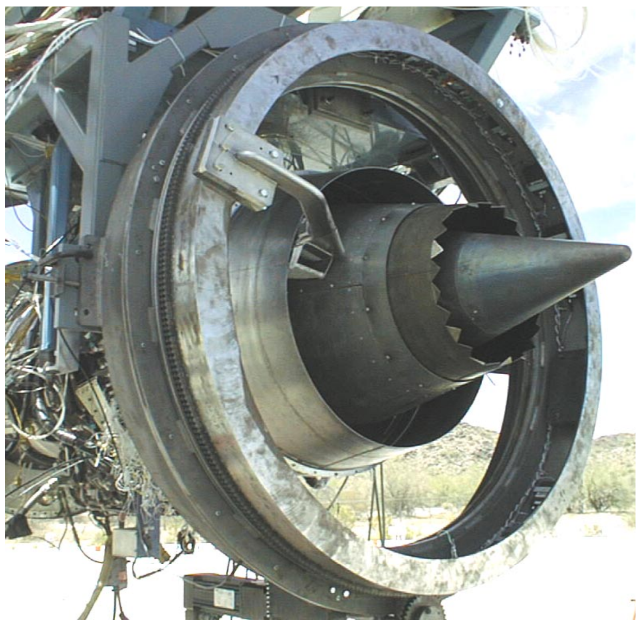
CF34-8C

Acoustic Benefit from Engine Static Test Confirmed Noise Reduction Measured in Scale Model Tests

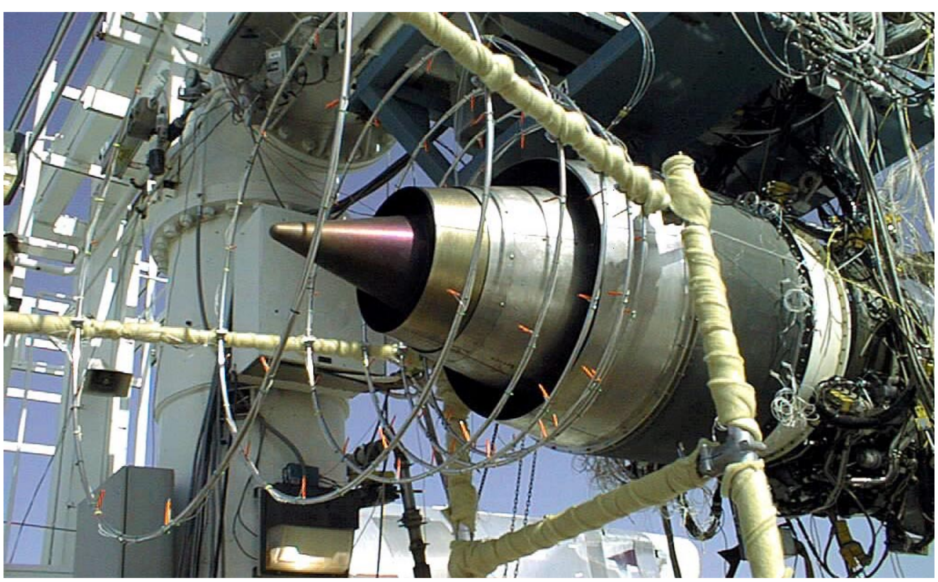
Honeywell Engines and Systems

Contact: don.weir@honeywell.com

NASA Glenn, NASA Langley, Honeywell, and Boeing conducted acoustic modal measurements in the aft-fan duct of a Honeywell TFE731-60 engine as part of the NASA Engine Validation of Noise Reduction Concepts. Three innovative measurements techniques were applied: the aft duct rotating rake from NASA Glenn, 63 in-duct microphones in 3 cylindrical and 1 spiral array from NASA Langley, and a external "cage array" with 103 microphones from Boeing.



NASA Glenn aft-rotating rake installed on a Honeywell TFE731-60 engine.



Boeing cage array behind the Honeywell TFE731-60 engine with NASA Langley aft fan duct Kulites installed.

NASA Glenn Research Center

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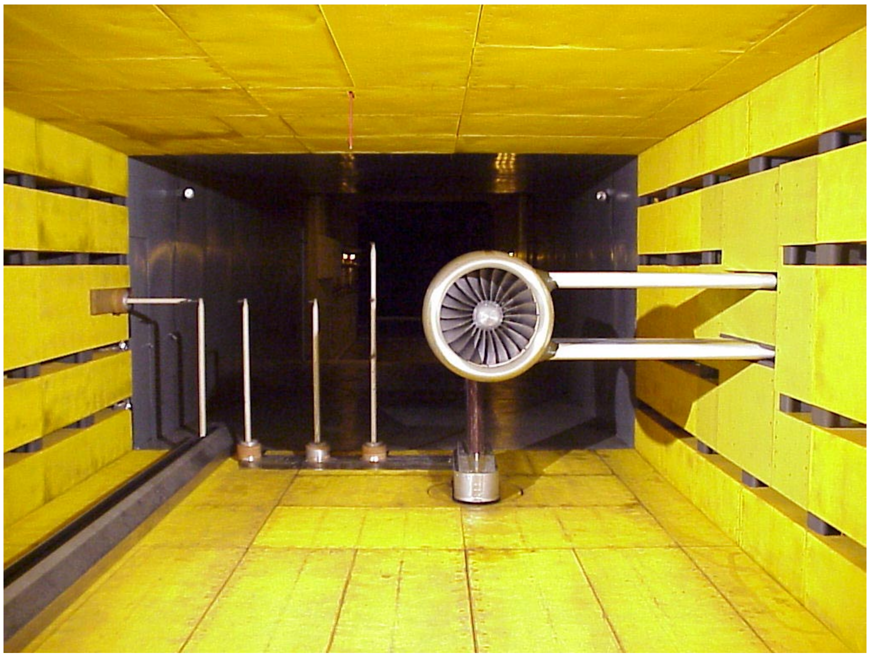
The NASA Glenn Research Center continued engine noise research through the Aerospace Propulsion and Power Base Program (which includes the previous Advanced Subsonic Technology Noise Reduction Program). The Third Computational Aeroacoustics Workshop for Benchmark Problems was hosted at the Ohio Aerospace Institute where over 65 people from around the world participated in providing numerical solutions to various model problems relevant to engine noise. Fan research included a rotor-alone noise assessment using a self-centering nacelle suspension system that successfully maintained stringent fan tip clearances. New data including aerodynamic performance, unsteady surface pressures on various stators, two-point hot-wire flow measurements near the fan, duct mode measurements and sideline acoustic data were obtained to provide diagnostic information on fan noise sources. A new small hot jet rig was installed in the Aeroacoustic Propulsion Laboratory that will be used for future fundamental studies in jet noise. The larger, Nozzle Acoustic Test Rig (NATR) was used to obtain Particle Image Velocimetry (PIV) data for several nozzle configurations representative of subsonic turbofan engines. Subsonic engine noise reduction concepts are being are being evaluated for the new Quiet Aircraft Technology (QAT) Program that will start in 2001.



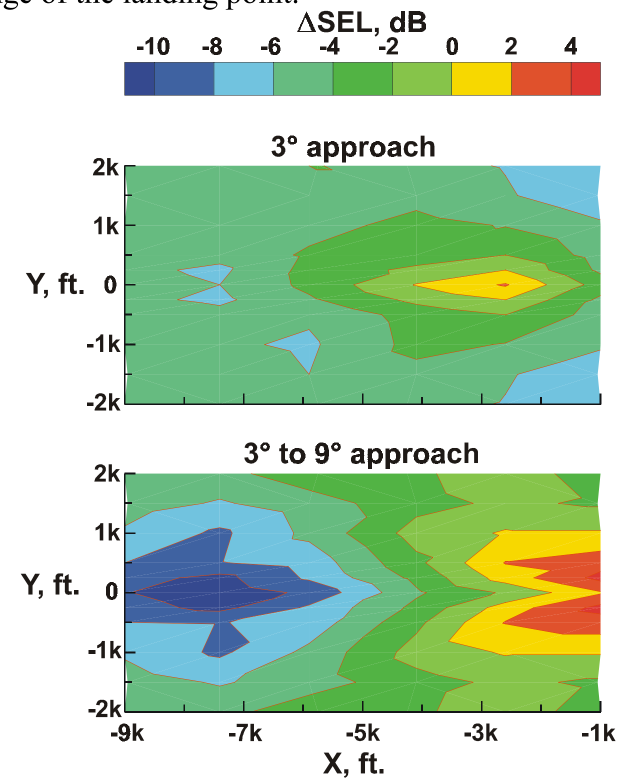
Rotor-Alone Fan Test Installed in NASA Glenn's 9'x15' Wind Tunnel

NASA Langley Research Center

Contacts: (see specific sections)

Tiltrotor Terminal Area Flight Procedures

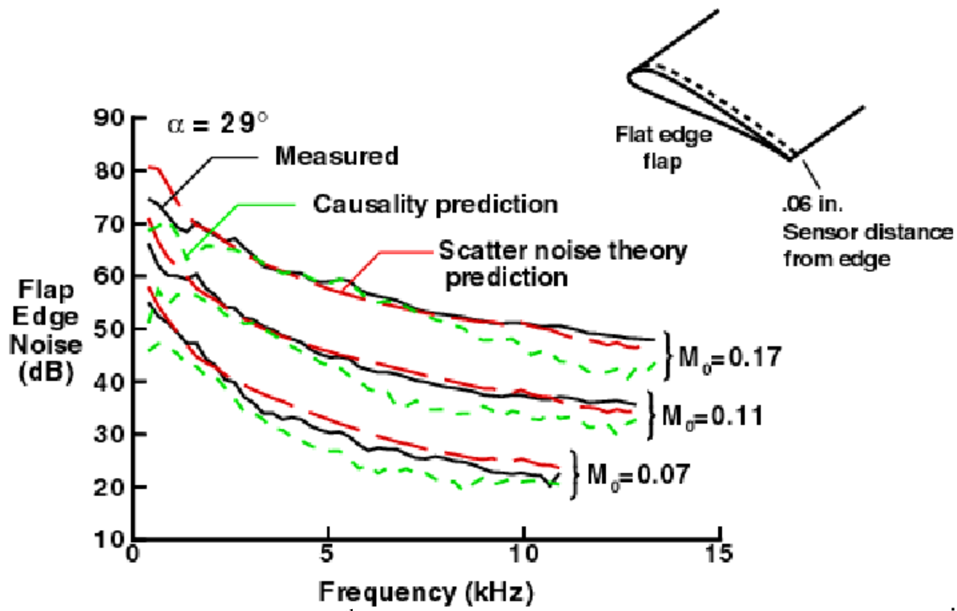
The third in a series of three XV-15 low noise terminal area operations flight tests was conducted in October 1999, at Waxahachie, TX, by the NASA/Army/Bell Helicopter test team. The purpose of the flight test program was to develop safe, low noise terminal area flight procedures for tiltrotor aircraft by optimizing the nacelle angle, airspeed, and glide slope schedules to reduce the noise footprint while fully coupling handling qualities requirements with noise reduction. The microphone array consisted of 37 ground board mounted microphones that were deployed over a 367-acre area. Compared to the "baseline" 6° approach, the 3° approach provided a relatively uniform noise reduction of 4 to 6 SELdB over most of the measurement area while a 3° to 9° segmented approach profile provided more than 10 SELdB noise reduction near the centerline, between 6000 and 9000 feet up-range of the landing point.



NASA Langley Contact: David A. Conner (d.a.conner@larc.nasa.gov)

Airframe Noise Studies

Airframe Noise studies in NASA Langley's Quiet Flow Facility (QFF) provides validation that shear layer instability and related pressure scatter is the dominant flap-edge noise mechanism. The figure shows that measured flap -edge noise compares well with scatter noise theory predictions and causality-based predictions, using unsteady surface pressure sensor results at the flap edge.



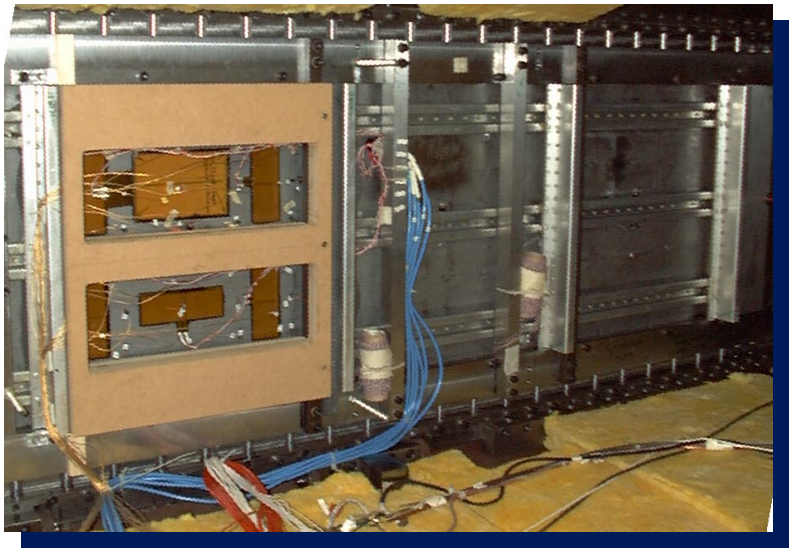
The results were presented at the 6th AIAA/CEAS Aeroacoustics Conference as Paper No. 2000-1975.

NASA Langley Contact: Tom Brooks (t.f.brooks@larc.nasa.gov)

Structural Acoustic Control System

NASA, Virginia Tech and Raytheon engineers have successfully demonstrated a second generation active structural acoustic control system employing a principal component based real time controller and optimized transducer locations on a Raytheon 1900D commuter aircraft. Reductions of 14 dB on the BPF and 3-5 dB on the higher harmonics were attained in flight.

Active control system tested on Raytheon Beech 1900D aircraft



Aircraft panel installed in AEDC von Karman Tunnel A.

Engineers at NASA Langley have reduced the transducer requirements for active structural acoustic control of turbulent boundary layer noise on realistic aircraft panels to a single sensor input and a single piezoceramic actuator while maintaining effective broadband control. Previous results in an AEDC wind tunnel at Mach 0.8 and 2.5 reduced total radiated sound 10-15 dB at resonances and 5-10dB over 150-800 Hz.

NASA Langley Contact: Richard Silcox (r.j.silcox@larc.nasa.gov)

Ducted Fan Noise Prediction Code

The Langley ducted fan noise prediction code TBIEM3D based on the boundary integral equation method (BIEM) has been added two new capabilities. The flow Mach number inside the duct can be different from the flight Mach number. In addition, the noise from a ducted fan having a co-annular duct with segmented liner can be predicted. The code calculates the noise from rotating dipoles inside a finite and infinitely thin circular duct in uniform forward flight. The duct propagation and radiation are treated in a unified manner using BIEM without the need of the knowledge of the inlet and exhaust impedances.

NASA Langley Contact: Feri Farassat (f.farassat@larc.nasa.gov)

Nacelle Liner Impedance

In-situ control of nacelle liner impedance is an attractive possibility, both for liner developmental testing and eventually for in-flight applications. Work at Boeing, Georgia Tech, and NASA Langley Research Center (LaRC) have focused on understanding bias flow as a means of effecting in-situ liner impedance changes. These efforts have generated mixed results. Purely experimental efforts at Boeing showed no significant impedance change due to bias flow, yet a Georgia Tech experiment showed significant improvement in normal incidence absorption with the aid of bias flow. Work conducted by Virginia Consortium of Engineering and Science Universities (VCES) at LaRC focused on the collection of a quality database of impedance data for a range of perforates with open area ratios ranging from 0.05 to 0.12. This database was used to determine the relative performance of various perforate impedance models, and to demonstrate that including bias flow in the design of an optimized two-layer passive liner provides improved broadband normal incidence acoustic absorption.

NASA Langley Contact: Tony Parrot (t.l.parrott@larc.nasa.gov)

Noise Abatement Procedures

The highly instrumented NASA LaRC 757 research aircraft was used to fly an assortment of approach and departure procedures over an array of ground based microphones. The purpose was to quantify, under controlled and recorded circumstances, noise benefits resulting from advanced noise abatement procedures which can be flown by current jet transport aircraft using existing avionics equipment.

Both departure and approach procedures were flown over microphone arrays located beneath the aircraft flight trajectory. Baseline procedures for both the departure and approach scenarios were established using Boeing operational recommendations. Variations of both the departure and approach scenarios were then flown over the same arrays. A database containing the far field acoustics measured from each procedure has been constructed. The resulting acoustics database is time correlated with databases for 1) the positions of aircraft controls, control surfaces, and engine parameters, 2) differential GPS aircraft tracking, and 3) weather conditions for each flight test procedure. The differential GPS was used in real time to determine that the planned aircraft trajectory was achieved and a third person was stationed in the jump seat of the aircraft cockpit to insure that the various procedures had been properly executed.

The flight test was run in April 2000 at the Airborne Airpark airport facility in Wilmington, Ohio. This airport facility can support large jet aircraft, has a low air traffic volume during daylight hours and hence, has a relatively low noise background during the needed operational hours.

NASA Langley Contact: Robert Golub (r.a.golub@larc.nasa.gov)

Jet Noise Database

A large database of noise from ultra-high bypass ratio co-annular jets was collected using the Jet Engine Simulator in the Low Speed Aeroacoustic Wind Tunnel at NASA Langley. The directional data included bypass ratios up to 14, forward flight simulation up to Mach 0.28, and generic cycle lines representative of conditions from takeoff to cutback. In addition to test points along the cycle lines, parametric variations off the line were taken. The data is being used to extend an existing semi-empirical, dual-flow jet noise prediction code to higher bypass ratios.

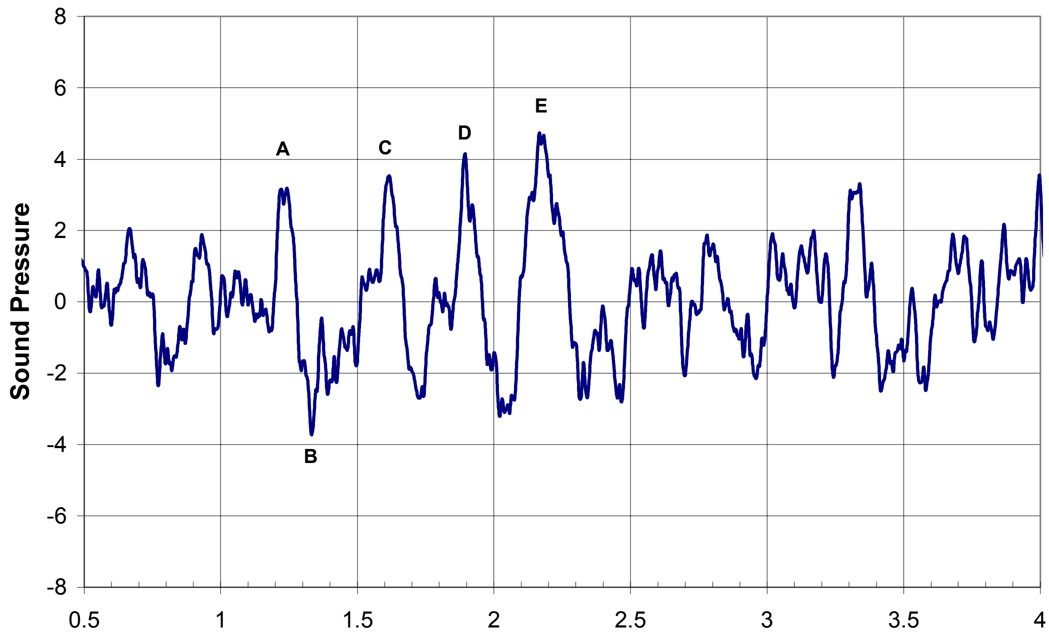
NASA Langley Contact: Tom Norum (t.d.norum@larc.nasa.gov)

Ohio State University

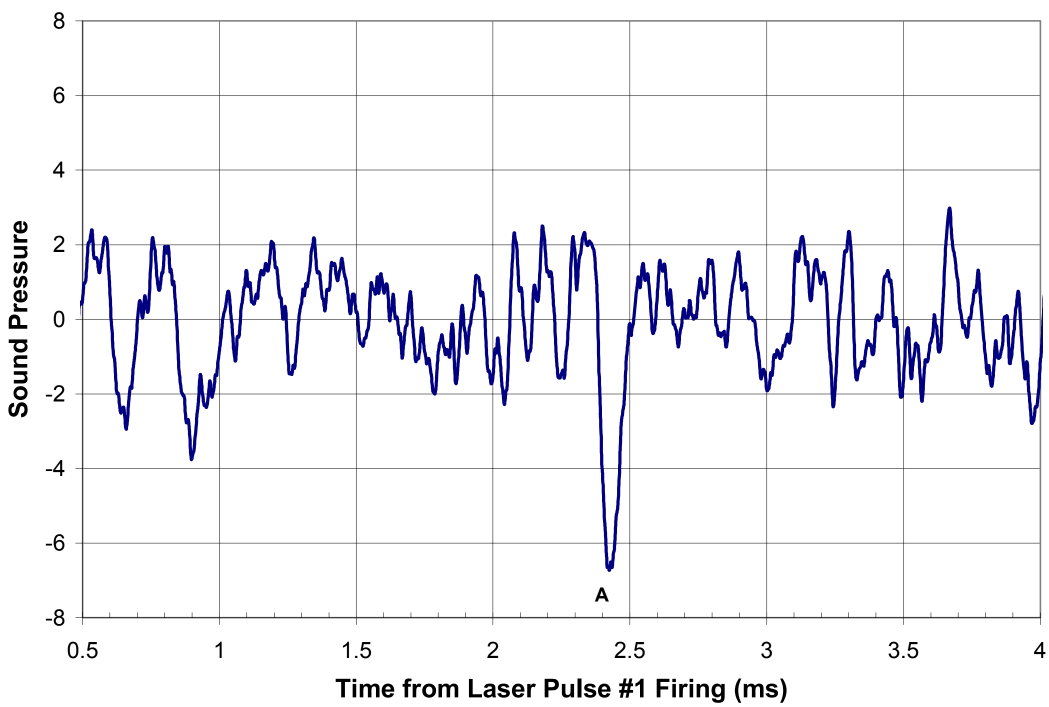
Contact: Mo Samimy (samimy.1@osu.edu)

We used simultaneous noise measurements using two microphones in the far field and flow visualizations using laser sheet lighting in an attempt to identify noise sources (e.g. interaction among turbulence structures) in a Mach 1.3 ideally expanded jet. Figure 1 shows two time traces of the normalized sound pressure that was recorded by the front microphone of the dual microphone array. The time trace of the pressure ratio in Figure 1(a) shows a sinusoidal signal between 1.5 and 2.5 ms with a period of approximately 0.3 ms that lasts for three periods of the oscillation. In addition to groups of oscillating, large amplitude, seemingly related peaks, there were also individual large amplitude peaks. Figures 1(b) shows such an example of a large amplitude sound pressure ratio peak. The large peak is not a crackle-type noise, as the Mach number is too low, and the skewness of the data was below 0.1. Also in Figure 1(b), the time range from 1.0 to 2.0 ms for the front microphone has no large amplitude pressure ratio peaks. This is a large period of time without any significant sound events (a large-scale structure would travel nearly 8 jet diameter distance over this time period). There is also a similar period of relative quiet between 2.5 and 3.1 ms. Regions that did not have any large-amplitude sound waves over long periods were observed in many of the other time traces.

The goal of this portion of the research was to relate these noise events to flow processes. However, visualizations based on a double-pulse laser proved to be inadequate. Currently we are in the process of developing a laser and a camera system that we can use to obtain up to 16 pulses and thus 16 consecutive images with an inter-image time separation as small as 1 microsecond. This system will be ready in a month and we are hoping to utilize it for the identification of flow processes that generate the noise events shown in Figure 1.



A
B
C
D
E
Sound Pressure
8
6
4
2
0
-2
-4
-6
-8
0.5
1
1.5
2
2.5
3
3.5
4

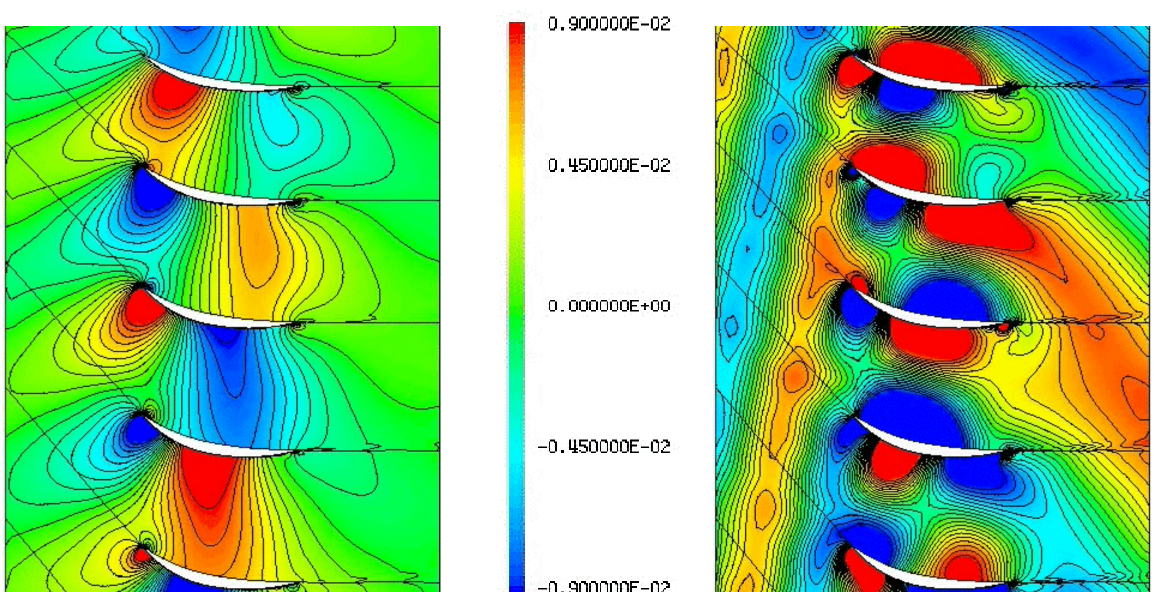


A
Sound Pressure
8
6
4
2
0
-2
-4
-6
-8
0.5
1
1.5
2
2.5
3
3.5
4
Time from Laser Pulse #1 Firing (ms)

Pratt & Whitney

Contact: Wes Lord (lordwk@pweh.com)

A three-dimensional, linearized, unsteady aerodynamic analysis has been developed for aeroacoustic design applications. This analysis, called LINFLUX is based on the Euler equations and has been applied to predict the aeroacoustic response of the 22" Advanced Ducted Propulsor (ADP) Fan Exit Guide Vane (FEGV) to rotor wake excitations. The blades of the FEGV are highly three-dimensional, with twist, bow and flare at the tips. In predicting the unsteady response of this blade row, measurements taken downstream of the ADP rotor at NASA Glenn Research Center, together with empirical correlations were used to determine the strength and circumferential variation of the viscous rotor wake excitation. Numerical runs were carried out for disturbances at the first two multiples of the blade passing frequency (BPF). Sample results for the 1- and 2-BPF excitation are presented in Figures 1(a) and 1(b), which illustrate contours of the unsteady pressure at 94%-span. In the former case, the acoustic field is damped (cut off) upstream and downstream of the blade row while in the latter, propagating acoustic responses occur at both inlet and exit. Further analysis shows that four such acoustic modes are present at the inlet and exit, indicating a rich spectrum. Based on the numerical solution for the unsteady flow in the blade row, the total downstream sound power level was determined to be 125.4 dB, which agrees well with the value measured experimentally at NASA Glenn. Although this agreement is somewhat fortuitous in view of the approximations that were made, it indicates that the modeling approach is viable as an analysis tool for future design systems. Furthermore, it may be profitably employed to provide an understanding of the unsteady flow physics associated with blade-row noise generation.



(a) (b)

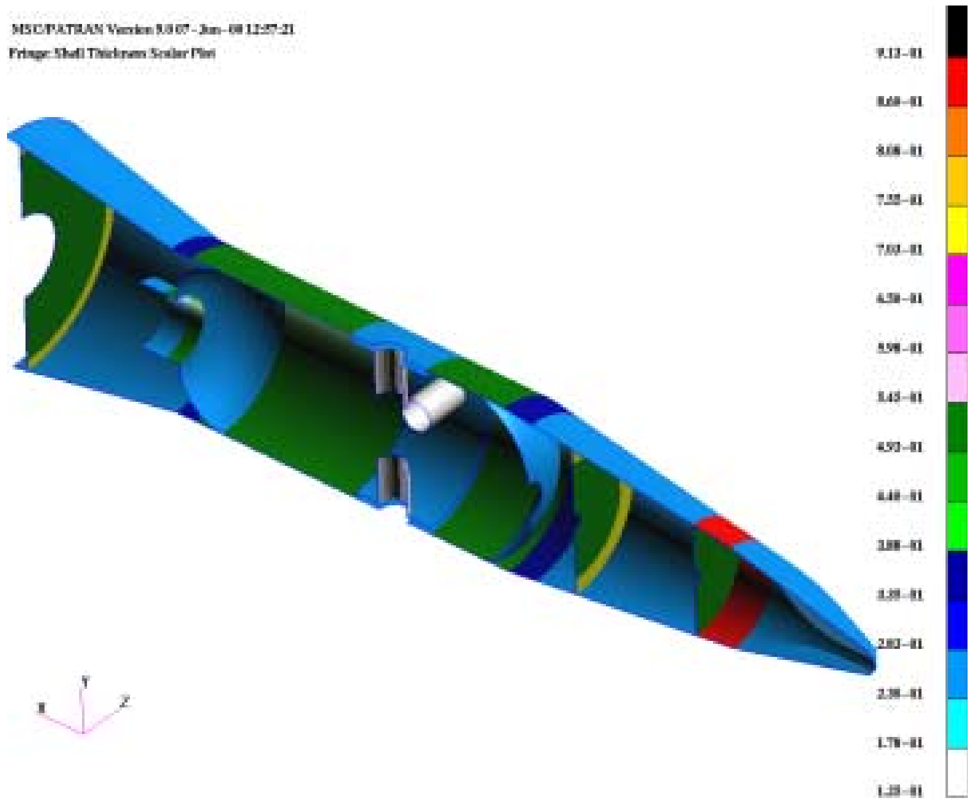
Figure 1. Unsteady pressure response of the ADP FEGV at 94%-span at (a) 1-BPF, and (b) 2-BPF. The excitation amplitudes were determined from NASA Glenn experimental data. It is evident that the response is cutoff in case (a), while propagating disturbances appear at inlet and exit in case (b).

The University of Mississippi

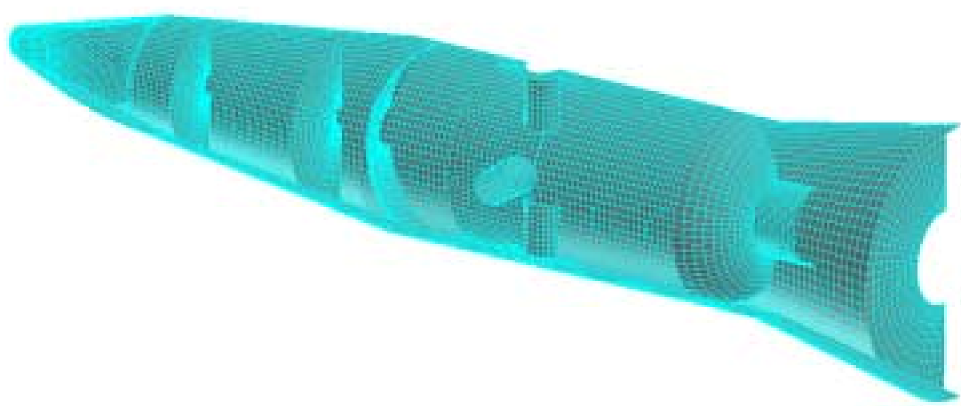
Contact: Jack Seiner (jseiner@olemiss.edu)

CRAFTech, CALSPAN at The University of Buffalo, and The University of Mississippi, conducted a numerical/experimental study on interceptor missile vibrations with side steering control jets. The predictions were found to be consistent with prior data on maneuvering reentry vehicles. This technology is applicable to the NASA program on Reusable Launch Vehicles, where sensitive payloads and vehicle performance must be optimized.

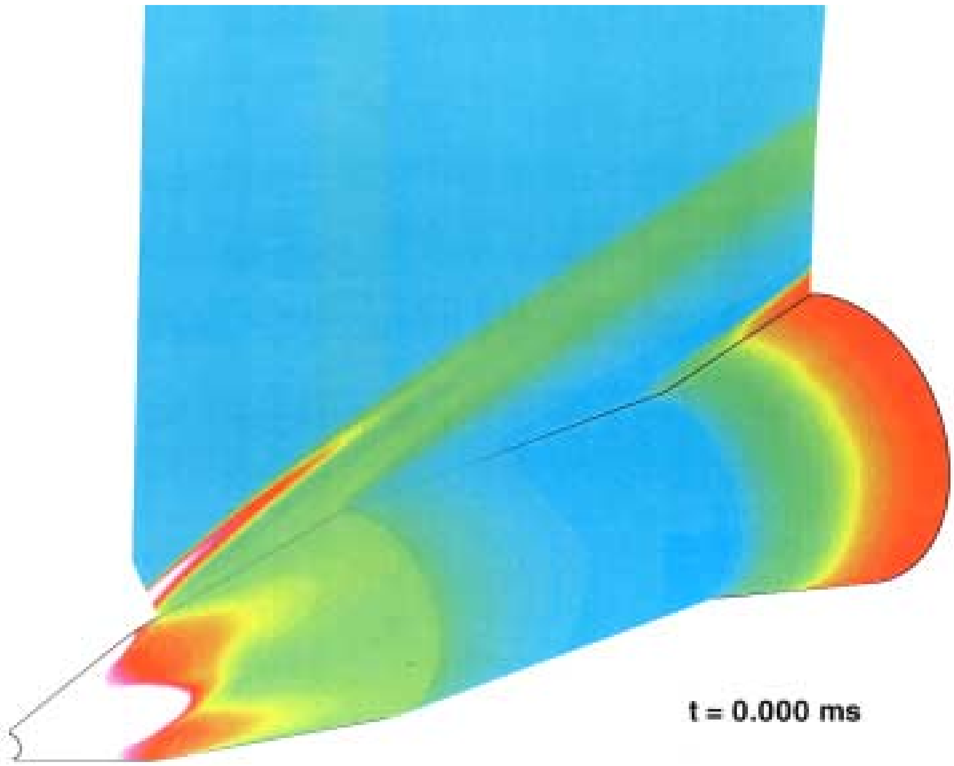
Atmospheric Interceptor Vehicle with Solid Propellant Divert Attitude Control System.



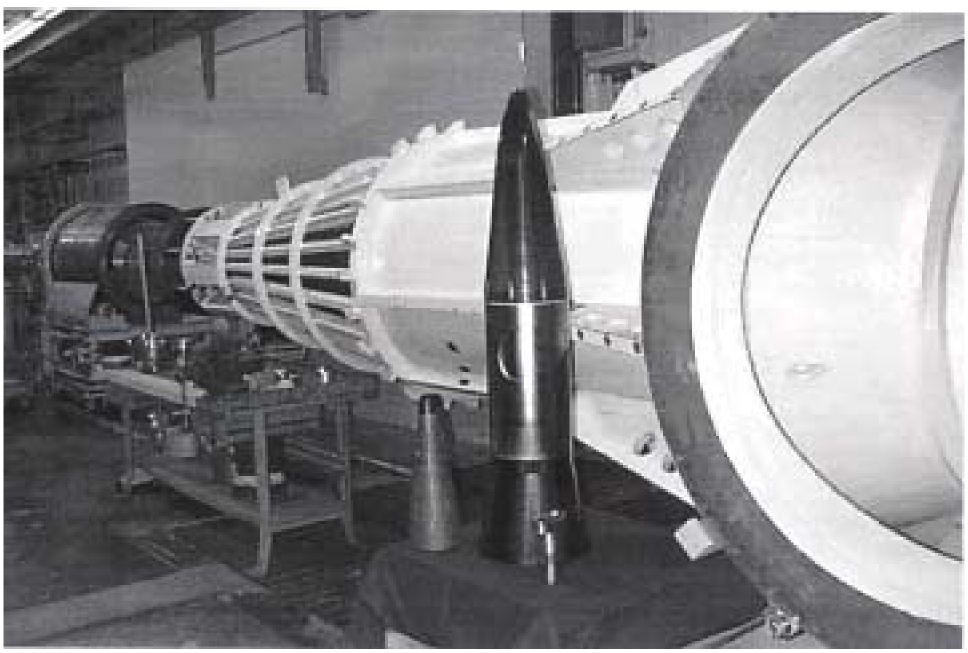
Solid Model for FEM Analysis



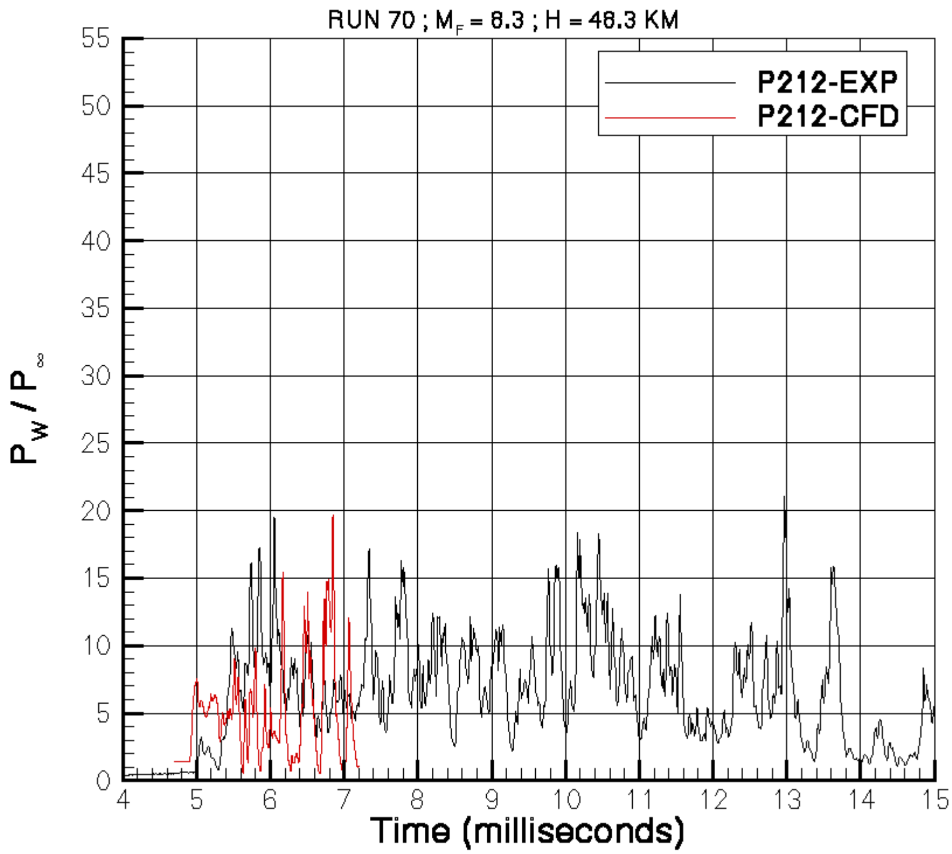
FEM mesh.



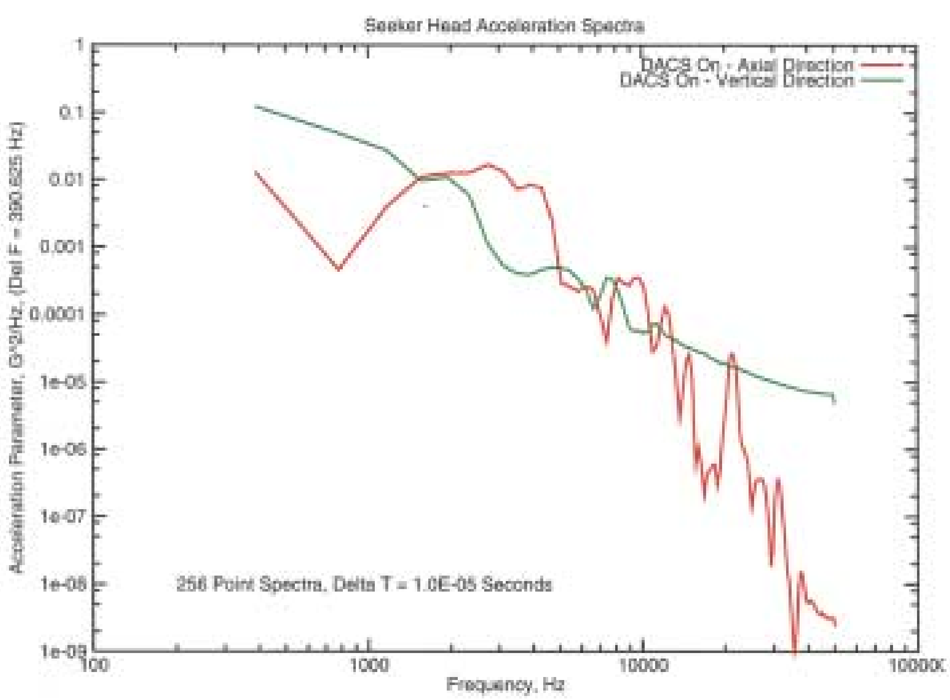
Predicted surface pressures before ignition of control jet.



AIT Vehicle in LENS facility.



Predicted and measured dynamic surface pressure.



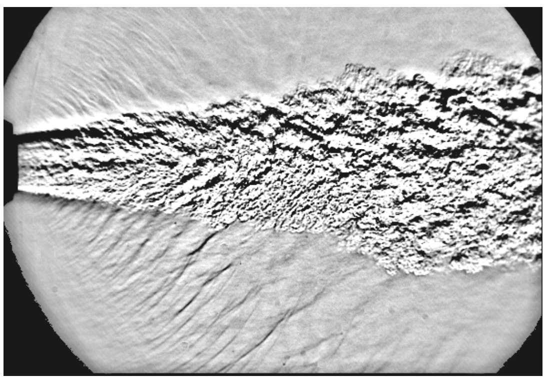
Predicted seeker head acceleration spectra.

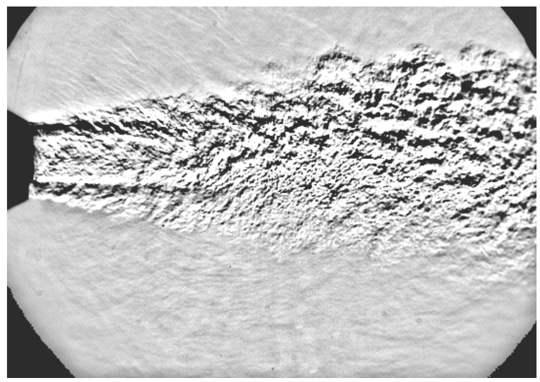
University of California Irvine

Contact: Dimitri Papamoschou (mailto:dpapamos@uci.edu)

Directional Suppression of Noise from Supersonic Jets

Research by Dr. Dimitri Papamoschou at U.C. Irvine has demonstrated substantial noise reduction from supersonic jets by enveloping the lower part of the jet with a parallel stream of air. Noise towards the ground is reduced by up to 18 decibels using a simple and efficient nozzle arrangement. This project has been funded by NASA and applies to the development of future supersonic transports. The pictures below illustrate the technique: on the left, a supersonic jet emits Mach waves which are the dominant source of noise; on the right, addition of a layer of air below the jet eliminates the downward-emitted Mach waves.





UCLA

Contact: Jonathan Freund (jfreund@taylor.seas.ucla.edu)

Jonthan Freund's group at UCLA has continued their work identifying and modeling jet noise mechanism in supersonic and subsonic jets using first-principles computations. While such simulations are naturally limited in Reynolds number, the results show excellent agreement with experiments and are uniquely suited to study the physics because they provide full space- and time-resolved flow field data along with the acoustic field. In collaboration with Tom Bewley at UCSD, these same databases are now also being used to develop jet noise control strategies. A new simulation of the near-nozzle region of a jet is also underway which complements ongoing jet shear layer noise experiments being conducted by Mo Samimy's group at Ohio State to identify the flow mechanism that lead to particularly noisy events.

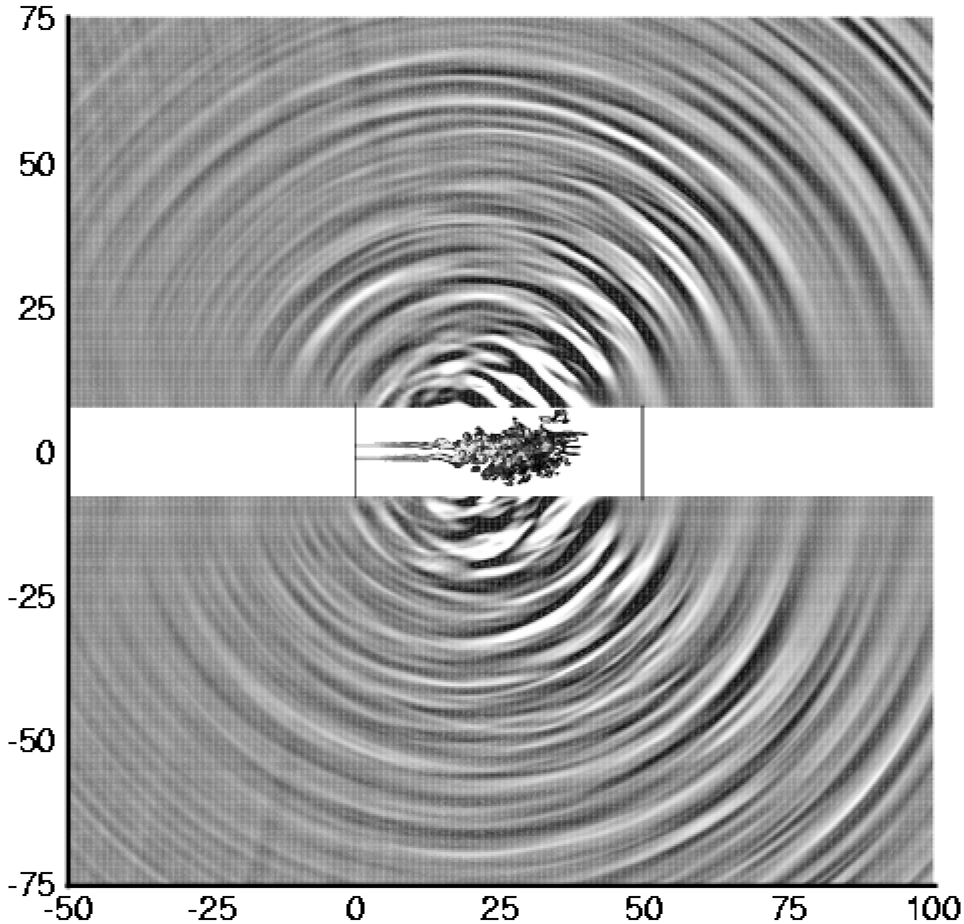


Figure 1. Visualization of a round jet first-principles simulation. The jet turbulence is visualized with contours of vorticity magnitude and the noise is visualized with gray-scale levels of divergence of velocity. The vertical lines demark the extent of the Navier-Stokes computational domain, the right third of which is an absorbing boundary zone.

United Technologies Research Center

Contact: David R. Polak (polakdr@utrc.utc.com)

UTRC made significant progress in cabin noise prediction and jet noise. For cabin noise, the SEA technique was analytically extended and applied to Sikorsky S-92 sidewall and interior panel sections. This included a novel approach of coupling SEA and FEA for extending interior noise predictions to the mid frequency range. Good experimental agreement was achieved for component transmission losses, subsystem response, and interior acoustic levels. For jet noise, a comprehensive acoustic and flowfield database was generated for high subsonic jets, and a procedure for extrapolating model scale noise reduction concepts to full scale PNL was developed. In parallel, jet noise sources were studied with a linear phased array and turbulence probes. To accomplish source localization, a new phased array processing algorithm was developed which achieved a 20-dB sidelobe rejection and a 5-degree beamwidth for 1 to 33 kHz (Figure 1). Also, further LES calculations were performed for high velocity jet and diffuser flow, achieving good agreement with acoustic measurements for low to moderate frequencies.

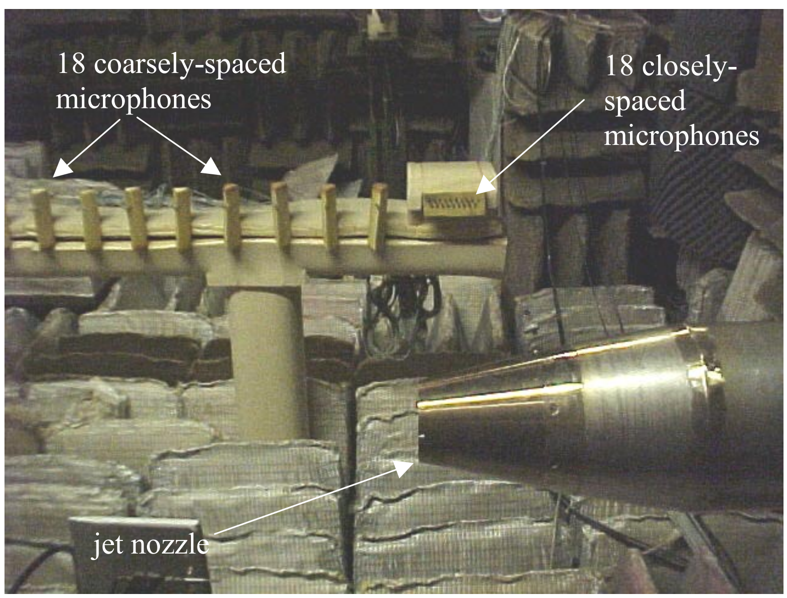


Figure 1: Photograph of UTRC's phased array with the jet model.